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Capabilities Aware Routing for Dynamic Ad-hoc Networks

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Abstract – *The objective of this research is to design and construct a useful routing protocol for an ad-hoc wireless network. While working primarily in the small, hand-held computing device arena, Bluetooth wireless technology has emerged as the network medium of choice. In this paper, we introduce Bluetooth wireless technology, examine current routing protocols, and present the objectives and considerations for the design of a new Bluetooth routing protocol. The protocol design will consider the capabilities of the devices (nodes) within the range of the network. It is envisioned that the Capabilities Aware Routing (CAR) protocol will make routing decisions based on such factors as device power constraints, memory, location and signal strength.*

Introduction

As the use of mobile wireless devices has continued to increase, so has the need to get the right information to these devices in a timely manner. Since these devices can vary substantially in terms of capabilities – memory, processing power, bandwidth, battery life and reliability – it is important that the information being delivered to these devices is useable.

The research being presented in this paper is our attempt at designing an efficient way of routing information in a small wireless network comprised of devices with varying capabilities. The wireless medium that has been chosen for this research is Bluetooth. Bluetooth is low power, short-range communication technology that is available for many Personal Digital Assistants (PDAs) and notebook computers. It is the opinion of the research team that any routing protocols developed in this effort can be tweaked to perform in a broader, more robust wireless environment in the future.

In this paper, we will present an overview of Bluetooth technology and why it is appropriate for this research. Also, we examine current wireless routing protocols, present the concept of device profiling and discuss the Capabilties Aware Routing (CAR) protocol that routes information based on the characteristics of networked wireless devices. Finally, we present ideas for extending CAR to increase the robustness and usability.

KIMAS 2003, October 1-3, 2003, Boston, MA, USA.

Overview of Bluetooth Wireless Technology

Bluetooth is low power, short-range communication technology that is available for many PDAs and notebook computers. Bluetooth operates in the 2.4 GHz free Industrial Scientific and Medical (ISM) band. Devices using Bluetooth technology connect in an ad hoc fashion allowing a collection of devices to form small networks called *piconets*. The device that establishes and coordinates a piconet is called the *master*. All other devices in the network are called *slaves*. A piconet consists of one master node and up to seven slave nodes. Communication within a Bluetooth piconet is limited to master-slave. All communication between slave nodes must pass through the master node. Since the master controls the communication within the piconet, all nodes are coordinated to the master's clock and share the same frequency hop sequence. The master transmits in the even numbered slots and the slaves transmit in the odd numbered slots. The master controls how the available bandwidth is divided among the slaves, using a Time Division

Multiplexing (TDM) scheme. [3]

The formation of a *scatternet* occurs when independent piconets overlap in coverage area and share a common node. *See figure 1.* Since each piconet has a unique master, each piconet, therefore, has its own frequency hop sequence.

Though the Bluetooth specification limits the number of slaves in a piconet to seven, the use of a scatternet can increase coverage area. When a device is present in more than one piconet, it is called a shared slave and must time-share, i.e. spend a few slots in one piconet and a few slots in the other. A Bluetooth unit can act as a slave in two piconets, but only as a master in a single piconet.[3]

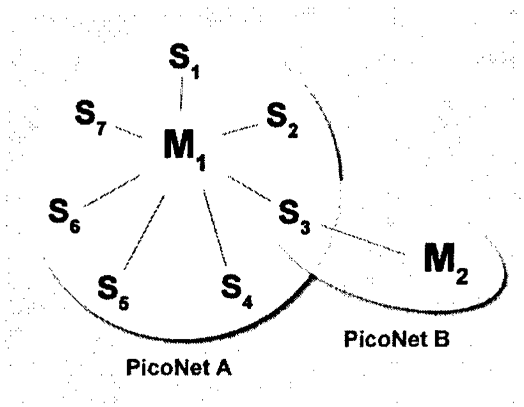

Figure 1 – Bluetooth scatternet

Master/Slave Discovery—In a Bluetooth piconet, the master/slave relationship is not initially apparent. It is very important to this research to determine the controlling node of individual piconets as routing among piconets depends on the network configuration.

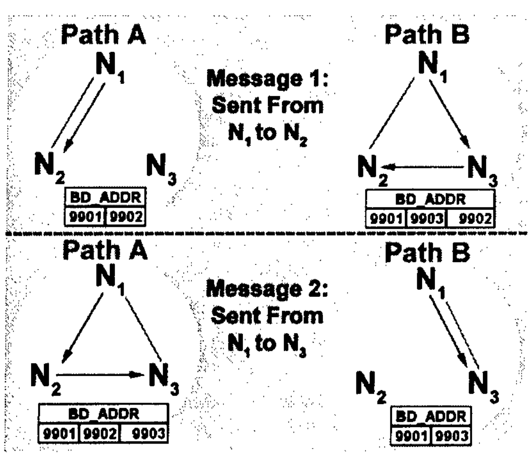

Figure 2 – Discovering the master node

For discovery of the master node of a piconet, it is necessary to operate in a static environment of three Bluetooth nodes (N_1, N_2, and N_3). By tracking the Bluetooth Device Address (BD_ADDR) of the message path, we can determine the master of the piconet. The BD_ADDR of the sender and receiver nodes will be recorded in an array as the message travels through the network. The initial message will be sent from N_1 to N_2, and the path of the addresses visited will be noted. Since slave-to-slave communication is prohibited, if the BD_ADDR of N_3 is in this array, then it is determined that N_3 is the master. If the BD_ADDR of N_3 is not in the array, but only N_1 and N_2, a message from N_1 to N_3 would be required to complete the discovery. If this array of Bluetooth addresses has the device address of N_2 in the middle of N_1 (sender) and N_3 (recipient), then N_2 is the master. Lastly, if this message does not have N_2 in the middle, then N_1 is the master of the piconet.

Sniff Mode and Park Mode—A master has the ability to assign a slave in to sniff or park mode. When the slaves of a piconet enter sniff or park mode, their participation is then limited. In sniff mode, the slave retains its Active Mode (AM) address and periodically listens for net traffic. During park mode, a slave gives up its AM address for a Park Mode Address (PM_ADDR) [10]. The advantage of park mode is that the node listens for net traffic at regular intervals and is allowed to maintain connection to the master. Parked slaves are also permitted to participate in other piconets.[8]

Why Bluetooth?

The decision to use the Bluetooth environment as a platform for this research was based on several factors. Bluetooth is a low power wireless network connection that allows for transfers of up to 1 Mb/s. Because of the fact that Bluetooth communication requires very little power, many different devices can participate. Bluetooth devices connect to each other in an ad-hoc fashion, which allows for easy and dynamic network creation. One other advantage of Bluetooth over other connection technology is that it is very inexpensive and many commercial PDAs are manufactured with built-in Bluetooth chips.

Bluetooth also has a variety of built-in security features that allow for secure connections with other devices. Built into Bluetooth is a frequency hopping spread spectrum (FHSS), hopping sequence that each piconet must follow. This frequency hopping sequence operates in the

2.4 GHz range at 1600 hops/s. A user authentication provided by Bluetooth, enables users to establish a secure connection and approve of only trustworthy devices. The use of encryption enables device connection with a 128 bit encryption key.[6]

Because of the limited range of Bluetooth (10-100 meters), it is possible to test networking ideas that could be extended to other wireless platforms, like 802.11b. Bluetooth testing can be done in one room, with a few cubicle walls or binders as the objects that restrict the devices. By choosing Bluetooth, it is possible to harness its uniqueness and advantages to produce useful results that can be extended to other forms of wireless communication.

Current Wireless Routing Protocols

Dynamic Source Routing (DSR) – DSR, developed in 1996 at Carnegie Mellon University, is based on the concept of source routing. This protocol uses the shortest path as routes are discovered on-demand. Every node maintains its own route cache containing the source routes that it knows about. If a node learns about a new route, it updates the entries in the route cache. DSR handles the route discovery and maintains the route. Route discovery begins with a broadcast query from the source node. Once the destination node is found, a reply from the destination node is propagated back to the source. In the DSR protocol each packet is required to maintain its route information, which eliminates the need for nodes to do periodic route discovery advertisements. Route maintenance involves notifying the source of packets in error.[7]

Ad Hoc On-Demand Distance Vector (AODV) - AODV is a routing protocol designed for mobile networks that allows nodes to pass messages through neighboring nodes to nodes that they cannot communicate with directly. AODV tries to find the shortest route, handles changes in routes and can create new routes when errors occur. Since nodes in wireless networks have a limited range, nodes cannot see all active nodes in the network and must hop through others to pass messages. AODV does this by instructing the active nodes to send HELLO messages at designated time intervals. When it is determined that the source node and a destination node are not within range for direct communication, a route request message is broadcasted. The route request contains important information about the source and the destination and the path being taken. AODV is able to adjust to the dynamic nature of ad-hoc wireless networks by injecting a route error message. Through examination of the routing tables, nodes can remove routes with dead nodes.[7]

To summarize AODV – the protocol finds routes only as needed, keeps track of the next hop for a route instead of the entire route, and uses periodic HELLO messages to track nodes within communication range.

Objectives and considerations for Capabilities Aware Routing (CAR)

When routing in a wireless network, it is important to keep in mind the limitations of both the communication medium and the devices in the network. Bluetooth networks require that information be passed through devices that act as nodes to get to the final destination. To find the best path to each destination you have to know the limitations of each device before you can choose which path to send the information. The battery life of the device, the distance the device is from all the devices it is connected to, the memory available to the device, the type of device and the dependability of the device are all important aspects to keep in mind when routing through Bluetooth.

The CAR protocol will be designed to find the best path for routing information to a destination based on the characteristics of the nodes in the path. While using many of the features of such noted routing protocols as Dynamic Source Routing (DSR) and Ad-hoc On Demand Vector (AODV) routing, CAR is envisioned as extending these protocols by evaluating the varying nodes in a Bluetooth scatternet and rating their overall ability to transport information packets. The nodes in our Bluetooth network can vary from simple devices such as printers or hubs to cell phones or PDAs to notebook or desktop computers. All of the different devices present challenges and opportunities for routing in a Bluetooth scatternet.

The theory behind this research is that if the nodes in the network knew of the characteristics of the other nodes, more efficient routing decisions could be made. Node characteristics such as processing speed, available memory, connection reliability, available bandwidth and remaining battery life could be evaluated for each node and used to reason about the best routing path. Device attributes will be classified and prioritized into a decision table where decisions about routes will be made. The attributes will be weighted and scored using specially designed algorithms, with the best score being the optimal route. Route comparison based on the scores and packet content will project an optimal path.

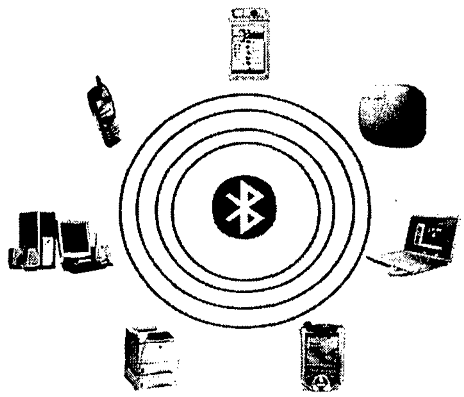

Figure 3 – Devices in Bluetooth network

Some of the device characteristics that might be of concern for this routing research include: remaining battery life of the device, proximity of devices to other devices, device allocated memory, allocated bandwidth, reliability of connection to each device and device type.

Remaining battery life – Each Bluetooth chip has a user-determined threshold where a connection shuts down when the battery life reaches a certain level. If a device has a large amount of its power remaining, or is plugged in, it would be more useful to connect to this device rather than a device that could possibly be dropped in the near future. If a device's battery power is low and it disconnects from the network, problems will certainly occur.

Device proximity – Knowing where in the network devices are located at an instant in time may be useful as a node may be on the fringe of the network and will lose connectivity very shortly. Although this may be quite difficult to determine, it would be convenient for a routing algorithm to be able to tell how close the device is to moving out of the range of the network.

Device memory – The available memory that a device has allocated at a particular time is an important factor that is considered for the CAR protocol. The device memory that is available can be accessed through Java code, by checking the runtime memory.

Allocated Bandwidth – When working in a small wireless environment using hand-held devices, limitations on bandwidth are inherent. Having knowledge about the current state of the active nodes of a Bluetooth scatternet with regards to transmission activity could be beneficial to the entire network. A scenario where a reliable node, with much memory and battery life, like a plugged-in notebook computer, may in fact be a bottleneck when compared to a relatively low powered cell phone, because of traffic flow. A routing protocol that has the intelligence to recognize where bandwidth problems may occur would have significant routing advantages.

Reliability – The protocol that is envisioned by this research group will have the intelligence to know the dependability of each particular node in the network. One attribute with regards to dependability that can be considered is length of time that a device has been active in the network. Being that our research platform is a highly dynamic environment, it is crucial to be able to predict which nodes can be projected to be available for service. The creation of a simple database could track the reliability of nodes based on length of time a node remains active in the network. Nodes that frequently enter and exit a network would be deemed less reliable than nodes that enter and remain active for longer periods of time.

Device Type – The devices to be used in this research project are quite diverse in range and capabilities. A route of more hops that consists of notebook computers may prove to be more efficient than a route of fewer hops that includes PDAs or cell phones. The main consideration is that a laptop or hub has a range that is about ten times greater than that of a PDA. Bluetooth has classified the following devices: Class 1 devices (laptops and hubs) have a range of up to 100 meters. Class 2 devices (USB Bluetooth adapters) have a range of up to 20 meters. And Class 3 devices (PDAs and cell phones) have a range of up to 10 meters. By transferring through devices that have a limited reach, there is an increased chance that a device becomes unreachable.

Future Research to Extend CAR

Virtual Node Theory (VNT) – One of the driving factors regarding the CAR protocol is the idea of maximization of the transport of information from one node to another within a Bluetooth network. Bounded by the limits of Bluetooth technology within a piconet, a minimum network path of one (1) is required for communication between master and slave, and a minimum network path of two (2) is required for communication between slave and slave. Master/slave communication is a straight-forward, "peer-to-peer-esk", environment. Slave/slave communication, on average, is more costly because of greater overhead required of the master node, and an additional hop in the network. But what if we removed the middleman and could communicate in a peer-to-peer type connection with two slaves?

One interesting topic of research that has emerged from the present research project is that of Virtual Node Theory (VNT). VNT is the process of two nodes within a piconet identifying each other as nodes interested in communicating. Once the nodes know of each other and agree on a way of identifying each other independent of their current piconet, a message is sent to the master. This message simply states that the nodes will be going into an inactive mode and are to be removed from the masters routing table. As well, this message is requesting that the master perform a virtual node "block" for a short period of time. Once the message is sent to the master, both nodes send themselves into an inactive mode. Because the master had received a message from the two nodes requesting a virtual node "block", the master creates virtual nodes to fill the remaining slots of its piconet. In essence, the master is telling itself that its piconet is full, and that it cannot accept anymore nodes. Once the virtual nodes are created, the two requesting slaves come out of sleep mode. Because the old piconet that the nodes just left is now full, the two are forced to negotiate with each other and form their very own piconet. Hence, this creates a peer-to-peer environment for communication.

Although this process appears straight-forward, it presents many obstacles and questions for interesting research and discussion:

Questions – Is there a necessity for Virtual Node Theory? Yes, if two nodes know that there will be heavy amounts of communication traffic between them. This will not only benefit the two nodes, but also the entire network by reducing traffic. How do we ensure that the two nodes coming out of inactive mode will not join another within-range piconet? This is a major concern. If the nodes join two different piconet's, neither of which they just left, then they will lose communication channels until they then locate each other again. What if there is too great a distance between the two nodes requesting a peer-to-peer, or virtual node "block"? Figure 4 below illustrates a major area of concern.

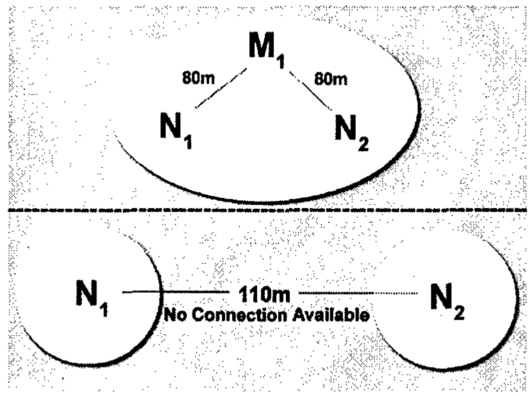

Figure 4 – Nodes not in range

If two nodes are connected to a master and they are in the same piconet, how do we ensure that once they leave that piconet that they will be within each other's range of communication? VNT is still in its infancy, and all of these questions need to be addressed. However, given the need for secure and/or frequent communication between two particular nodes in a Bluetooth network, it may be a useful area of discovery.

Bluetooth/802.11x Exchange – The most limiting factor of Bluetooth technology is range of communication. As discussed previously, we are limited to a maximum, best case scenario, of 100 meters for Class 1 devices. By combining wireless technologies (Bluetooth and 802.11x) and leveraging their individual strengths, it may be possible to limit power consumption and extend our network's reach. If a node requires access to resources outside its piconet or scatternet, it could extend its reach by finding a device (such as a laptop or desktop) in the network that has both Bluetooth and 802.11x capabilities.

By locating piconets and scatternets outside of its own, a node can take advantage of resources that it might have otherwise never known about. Because of advances in wireless programming and configurations like the J2ME MIDP 2.0, there is access to directory structures within wireless devices. This in turn, allows developers to store information in an area for both Bluetooth and 802.11x technologies to share. Once a resource is located outside a node's own piconet or scatternet, it locates the "gateway" to the other network with which it wishes to communicate. The "gateway" is the node that has dual communication modes, and can communicate with some other node in the distant network.

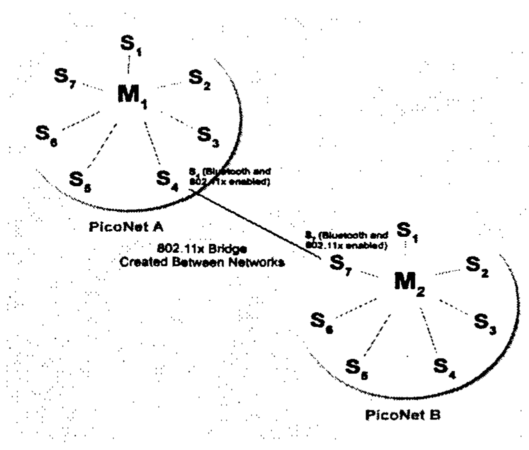

Figure 5 – 802.11x bridge between networks

The information is routed to the "gateway" node and stored in the device's file system. By utilizing the 802.11x technology, the dual mode device forwards the message or information to the remote network. From that point, normal CAR routing protocols could be utilized. The research team is in the process of implementing this technology, and hopes to have results confirming our belief of this extended capability.

Conclusion

A new idea for routing messages and information in a dynamic wireless ad-hoc environment was presented in this paper. *Capabilities Aware Routing* (CAR), offers a unique approach to transporting within a Bluetooth network. It is the opinion of the research team that by acquiring knowledge about the nodes in an ad-hoc network, and reasoning about that knowledge, more efficient routing will be observed. Also, by extending this technique through the use of *Virtual Node Theory* (VNT), and the *Bluetooth/802.11x Exchange*, even greater robustness and usability can be achieved. While the routing protocol ideas that have been presented are mainly theoretical, the intention to advance them into practical use exists.

References

[1] Sung-Ju Lee, "Routing and Multicasting Strategies in Wireless Mobile Ad-hoc Networks," UCLA dissertation for Doctor of Philosophy in Computer Science, 2000

[2] Ching Law Amar K. Mehta KaiYeung Siu, "Performance of a New Bluetooth Scatternet Formation Protocol," Massachusetts Institute of Technology

[3] The Bluetooth Special Interest Group (SIG), "BLUETOOTH SPECIFICATION Version 1.1" http://www.bluetooth.com, Feb 2001

[4] Balakrishna J. Prabhu and A. Chockalingam, "A Routing Protocol and Energy Efficient Techniques in Bluetooth Scatternets," Department of Electrical Communication Engineering, Indian Institute of Science, Bangalore 560012 India

[5] Morteza Maleki, Karthik Dantu, and Massoud Pedram, "Power-aware Source Routing Protocol for Mobile Ad Hoc Networks," Dept. of EE-Systems, University of Southern California

[6] Bruce Hopkins and Ranjith Antony, *Bluetooth for Java*, New York: Springer-Verlag New York, Inc., 2003

[7] Charles E. Perkins, Nokia Research Center, Elizabeth M. Royer, University of California Samir R. Das and Mahesh K. Marina, University of Cincinnati, "Performance Comparison of Two On-Demand Routing Protocols for Ad Hoc Networks", IEEE Personal Communications, February 2001

[8] Bray, Jennifer, and Charles F. Sturman. *Bluetooth 1.1: Connect Without Cables.* 2nd ed. New Jersey: Prentice Hall, 2002.

[9] Gurovski, Igor, and Velimir Karadzic. "Self Configuring Bluetooth Networks" http://www.connectblue.se/files/Selfconfiguring%20Bluetooth%20Networks.pdf, 2003.

[10] Palo Wireless, "Bluetooth Knowledge Base",http://www.palowireless.com/infotooth/knowbase.asp,2003